Aquatic fauna of the Warren bioregion, south-west Western Australia: Does reservation guarantee preservation?

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Abstract

The Warren Bioregion, in the extreme south-west of Western Australia, has a unique assemblage of aquatic invertebrates, fish and amphibians. Current literature indicates that 192 fully described species have been collected, of which 10 invertebrate, 1 fish and 6 frog species could be considered locally endemic. We estimate that secure nature reserves (A-Class and National Parks) in the Warren Bioregion provide a refuge for 86% of the aquatic faunal elements. Reservation alone, however, may not be sufficient to protect certain of the aquatic fauna. Adverse impacts occurring within catchments, including erosion and deposition of sediment, salinization, fire, land clearing, the presence of dams and the introduction of exotic fish, may adversely affect the aquatic fauna within a reserve. Management of protected habitats must ensure that only anthropogenic activities which are sympathetic to the long term persistence of all elements of the biota occur within, and adjacent to, the reserve systems.

Introduction

The natural landscape of the south-western corner of Australia is characterised by rivers which arise on an ancient and flat semi-arid inland plateau. From here, the rivers flow sluggishly towards the coast, before passing through a zone where the topography steepens and rainfall increases (Mulcahy *et al.* 1972; Churchward *et al.* 1988). Beyond this, the rivers again slow as they traverse the coastal lowlands, which feature extensive wetland systems and terminate in lagoon-like estuaries. Early settlers found the coastal lowlands to be largely infertile soils and used much of the area as pastoral land, preferring to use the rich alluvial soils along the rivers for intensive agriculture (Jarvis 1979). Pressures of urbanization and intensification of agriculture, associated with a burgeoning population in the century since colonization, have led to the loss of a large proportion of coastal wetland systems and many of those that remain have been altered from their natural state (see Halse 1989). A number of the larger rivers have been damaged through siltation and salinization, and many of the remainder are now impounded or subject to varied degrees of alteration through activities such as mining and logging (Olsen & Skitmore 1991).

The effect of these changes on the aquatic fauna cannot be fully assessed due to the lack of historical or baseline data. Locally or even regionally endemic aquatic species may have been lost from south-western Australia, or suffered substantial range reductions, particularly where these fauna were sensitive to changed hydrological regimes, increased eutrophication and/or salinization. This is evident in our aquatic environments today. Highly eutrophic wetlands contain few rare taxa, have high densities of "pollution tolerant" species and, overall, support an invertebrate composition which is distinct from that occurring in low to moderately enriched or coloured wetlands (Davis *et al.* 1993; Edward *et al.* 1994). The highly saline Hotham River and Thirty-Four Mile Brook, south-east of Perth, are dominated by salt tolerant crustaceans (60% total abundance), while insects contribute only 14% to the overall invertebrate composition (Bunn & Davies 1992). This situation is atypical of undisturbed streams of the jarrah forest, where insects usually comprise 70-80% of the fauna (Bunn *et al.* 1986), and was attributed to increased salinity (Bunn & Davies 1992). Williams *et al.* (1991) found little or no longitudinality in the faunal composition of the Blackwood River despite the presence of a distinct salinity gradient along its length. Although this could be interpreted as evidence of a halotolerant fauna, it may also indicate elimination of less tolerant fauna, which once characterised a more diverse system.

Public awareness of the need to conserve aquatic habitats has increased markedly over the last decade and this is reflected in the number of scientific studies that have been undertaken on wetlands, streams and rivers in the south-west since the mid 1980s (see Balla 1994). Considerable attention has been devoted to the aquatic fauna and their habitats in highly populated areas of the south-west, such as wetlands on the Swan Coastal Plain and streams in the adjacent jarrah forest, where monitoring to assess the impact of pollution or habitat change has often been the principal research or management objective (*e.g.* Storey *et al.* 1990; Bunn & Davies 1992; Growns *et al.* 1992).

Further south, the relatively undisturbed aquatic habitats within the Warren Bioregion (*sensu* Thackway & Cresswell 1995) have also provided a focus for scientific studies (*e.g.* Christensen 1982; Pusey & Edward 1990a, b; Horwitz 1996; Edward *et al.* 1994). This region is regarded as an important centre for endemism from a

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botanical viewpoint (Hopper *et al.* 1992), but its significance to the aquatic fauna has not been assessed in its entirety. This paper summarizes existing knowledge of the aquatic fauna in the Warren Bioregion and estimates the degree of endemicity found in the region. In addition, it presents a preliminary assessment of the reservation status of known aquatic species and makes recommendations for the ongoing protection of fauna within the reserve system.

Approaches

The aquatic invertebrates (>110 µm), fishes and amphibians which occur within the Warren Bioregion were compiled from published literature and museum records, and are therefore limited by the habitats examined and sampling protocol of these sources. The distribution of each species, determined from published literature, is described as either widespread, regionally endemic or locally endemic in accordance with Horwitz (1996). The reservation status of each species within the Warren Bioregion has been determined according to their presence or absence within reserves which fall under categories I and II of the World Conservation Union's classification of protected areas (Anon. 1994). This equates only to nature reserves (A-Class) and national parks which have the conservation of flora and fauna as a primary objective and require legislative provisions to alter their boundaries or status. Other forms of reserves in the region do not have this level of security and therefore have not been included in this study. We do, however, acknowledge that these other areas also play an important role in conservation. For the purpose of this study, a species which is described as reserved must have been recorded at least once in a secure reserve, as defined above.

To date, there have been no comprehensive surveys of aquatic invertebrates within all nature reserves and national parks of the Warren Bioregion and therefore the reference in Table 1 to species as absent from these reserve categories should be considered preliminary. In addition, species which are widespread or regionally endemic may not be found in nature reserves or national parks within this region, but may be found within similar reserves located elsewhere.

Although more invertebrate taxa are found in the Warren Bioregion than have been recorded in Table 1, many of these have not yet been described and specimens only exist in voucher or reference collections of individual researchers. To prevent confusion, whereby authors may have assigned different voucher names to the same taxon, only species for which published descriptions exist were considered here. Emergent adult invertebrates found in the vicinity of aquatic habitats were excluded because they could not be definitively linked with specific waterbodies. In addition, waterbirds have been excluded from this review, but information relating to their occurrence and reservation within the larger southern forest region may be found in Christensen (1992).

The tabulated information on aquatic invertebrates, fishes and amphibians provides a preliminary account of the level of endemism of aquatic fauna in the Warren Bioregion and emphasises the importance of the reserve system to both the restricted and more common fauna of the region.

Local endemicity in the aquatic fauna of the Warren Bioregion

Invertebrates

Aquatic habitats within the Warren Bioregion support a large proportion of invertebrate taxa which are endemic to south-west Western Australia, with approximately 17% of these considered locally restricted on the basis of surveys (Table 1). This number, however, may be an underestimate as only fully-described species have been considered, thereby excluding some taxa. There are, for example, only eight oligochaete species with widespread distributions shown in Table 1, yet there are at least a further four species which are restricted to the Warren Bioregion (Horwitz 1996) for which descriptions are pending (A Pinder *pers. comm.*). This situation may also extend to other groups, notably the dipterans and arachnids. Locally endemic invertebrates include the freshwater crayfish *Engaewa subcoerulea* and *E. similis* and the trichopteran *Kosrheithrus boorarus* (see Horwitz 1994; Growns & Davis 1994, respectively).

A rich suite of micro-crustaceans have been found in the area and, in the case of the copepods, this is highly distinctive (Table 1). Bayly (1992) examined temporary ponds near Northcliffe and identified several copepods which are locally endemic, including *Calamoecia elongata*, *Boeckella geniculata* and *Paracyclops* sp nov, as well as a unique form of *C. tasmanica* sl. In addition, the copepod *Hemiboeckella powellensis* is known only from Lake Powell, between Albany and Denmark (Bayly, 1979). Locally endemic cladocerans, *Biaptera imitaria* and *Daphnia occidentalis* were also found near Northcliffe by Bayly (1992). *Daphnia occidentalis* is a relictual species thought to have originated 70 mybp (Benzie 1986, 1988). This species was found in large numbers in a single pool, surrounded by swamp land within the D'Entrecasteaux National Park.

Fish

Eight species of freshwater fish are endemic to the south-west of Western Australia (Table 2) and four of these are now principally confined to the Warren Bioregion (Morgan *et al.* 1996). These include the Western Australian salamanderfish *Lepidogalaxias salamandroides*, a relictual Gondwanaland species (Allen 1982), which is now predominantly restricted to ephemeral pools within the coastal peat flats between Windy Harbour and Walpole (Morgan *et al.* 1996). The black stripe minnow *Galaxiella nigrostriata* and Balston's pygmy perch *Nannatherina balstoni* are similarly confined, although the former species is found in low numbers in a few lakes of the region, while the latter occurs in low numbers in both lakes and rivers of the region (Morgan *et al.* 1996). The mud minnow *Galaxiella munda* has the widest distribution of these four species, occurring in the headwaters and tributaries of rivers, as well as on the coastal peat flats (Morgan *et al.* 1996).

Disjunct and isolated populations of some of these

Table 1

Invertebrate fauna found in aquatic habitats within the Warren bioregion. Reservation status refers to their presence or absence in a nature reserve or national park within the bioregion. Distribution: W, widespread; RE, regionally endemic; LE, locally endemic. Sources; 1, Pusey & Edward (1990a); 2, Growns & Davis (1994); 3, Edward *et al.* (1994); 4, Bayly (1982); 5, Horwitz (1994); 6, Williams *et al.*(1991); 7, Bayly (1992); 8,Bayly (1979); 9 Harvey (1996); 10, Morton (1990).

Species[1]	Source	Lotic	Lentic	Reservation	Distribution
MOLLUSCA					
Hydriidae					
Westralunio carteri Iredale	2,3	√	√	+	RE
Glacidorbidae					
Glacidorbis occidentalis Bunn & Stoddart	1	√		+	RE
Ancylidae					
Ferrissia petterdi Johnston	1		√	+	W
Hydrobiidae					
Potamopyrgus niger Quoy & Gaimard	6		√	–	W
ANNELIDA					
Phreodrilidae					
Insulodrilus lacustris Benham	5		√	+	W
Insulodrilus nudus Brinkhurst & Fulton	5		√	+	W
Tubificidae					
Limnodrilus hoffmeisteri Cleperede	5		√	+	W
Naididae					
Pristina longiseta Ehrenberg	5		√	+	W
Pristina aequiseta Bourne	5		√	–	W
Dero furcatus Muller	5		√	–	W
Dero digitata Muller	5		√	+	W
Chaetogaster diastrophus Gruithuisen	5		√	–	W
ARACHNIDA					
Hydryphantidae					
Pseudohydryphantes doegi Harvey	5		√	+	RE
Aturidae					
Wheenyoides cooki Harvey	5		√	+	RE
Limnocharidae					
Limnochares australica Lundblad	5		√	+	W
Pionidae					
Australotiphys barmutai Harvey	9		√	+	RE
Larri laffa Harvey	9		√	+	RE
Piona cumberlandensis Rainbow	9		√	+	W
Arrenuridae					
Arrenurus sp nr *tasmanicus* Lundblad	5		√	+	RE
OSTRACODA					
Limnocytheridae					
Limnocythere mowbrayensis Chapman	1,3	√	√	+	W
Gomphodella aff *maia* De Deckker	3		√	+	W
Cyprididae					
Candonocypris novaezelandiae Baird	2,3	√	√	+	W
Newnhamia fenestra King	3		√	+	W
Cypretta viridis Thomson	7		√	+	W
Cypretta baylyi McKenzie	3,4,7		√	+	W
Eucypris virens Jurine	7		√	+	W
Kapcypridopsus asymmetra De Deckker	4		√	+	LE
Sarcypridopsis aculeata Costa	3		√	+	W
Alboa wooroa De Deckker	3		√	+	W
Ilyodromus candonites De Decker	4		√	+	LE
Ilyodromus varrovillus King	7		√	+	W
Bennelongia australis Brady	8		√	+	W
Candonidae					
Candonopsis tenuis Brady	3		√	+	RE
COPEPODA					
Centropagidae					
Calamoecia attenuata Fairbridge	1,3,7	√	√	+	RE
Calamoecia tasmanica Smith sl	1,3,7	√	√	+	W
Calamoecia elongata Bayly	7		√	+	LE
Hemiboeckella searli Sars	3,7		√	+	W
Hemiboeckella andersonae Bayly	3,7		√	+	RE
Hemiboeckella powellensis Bayly	8		√	+	LE
Boeckella geniculata Bayly	7		√	+	LE

Species	Source	Lotic	Lentic	Reservation	Distribution
Gladioferens imparipes Thomson	3		√	+	RE
Cyclopidae					
Macrocyclops albidus Jurine	1,7	√	√	+	W
Australocyclops australis Sars	7		√	–	W
Eucyclops spatulatus Morton	10		√	–	W
CLADOCERA					
Chydoridae					
Biapertura cf *macrocopa* Sars	4,7		√	+	W
Biapertura rigidicaudis Smirnov	4		√	+	W
Biapertura affinis Leydig	1	√	√	+	W
Biapertura longinqua Smirnov	7		√	+	W
Biapertura nr *setigera* Brehm	3		√	+	W
Biapertura imitatoria Smirnov	7		√	+	LE
Graptolebersis testudinaria Fischer	3		√	+	W
Camptocercus cf *australis* Sars	3		√	+	W
Chydorus barroisi Richard	4		√	+	W
Chydorus cf *sphaericus* O F Muller	7		√	–	W
Pleuroxus inermis Sars	7		√	–	W
Pleuroxus jugosus Henry	4		√	+	W
Alonella cf *excisa* Fischer	7		√	+	W
Rak obustus Smirnov & Timms	8		√	–	W
Monope reticula Henry	7		√	+	RE
Macrothricidae					
Neothrix armata Gurney	1,3,4,7	√	√	+	W
Daphniidae					
Simocephalus acutirostratus King	1,3	√	√	+	W
Daphnia carinata King sl	3		√	+	W
Daphnia occidentalis Benzie	7		√	+	LE
Scapholeberis kingi Sars	7		√	+	W
Bosminidae					
Bosmina meridionalis Sars	3		√	+	W
ISOPODA					
Amphisopidae					
Amphisopus annectans Nicholls	1,5		√	+	RE
Amphisopus ?lintoni Nicholls	1	√	√	+	RE
Hyperodesipus ?plumosus Nicholls & Milner	2	√		–	RE
AMPHIPODA					
Perthidae					
Perthia acutitelson Straskraba	1,2	√	√	+	RE
Perthia branchialis Nicholls	3		√	–	RE
Ceinidae					
Austrochiltonia subtenuis Sayce	3		√	+	W
DECAPODA					
Parastacidae					
Cherax quinquecarinatus Gray	3,5		√	+	RE
Cherax tenuimanus Smith	3,5		√	+	RE
Cherax preissii Erichson	5		√	+	RE
Cherax crassimanus Riek	5		√	+	RE
Cherax destructor Clark	3		√	+	W
Engaewa subcoerulea Riek	5		√	+	LE
Engaewa similis Riek	5		√	+	LE
Grapsidae					
Leptograpsodes octodentatus Milne-Edwards	5		√	+	W
Palaemonidae					
"Palaemonetes" australis Dakin	3,5		√	+	RE
ANISOPTERA					
Aeshnidae					
Aeshna brevistyla Rambur	3		√	+	W
Austroaeschna anacantha Tillyard	2,5,6	√	√	+	RE
Corduliidae					
Orthetrum caledonicum Brauer	3,5,6	√	√	+	W
Austrothemis nigrescens Martin	3,5		√	+	W
Diplacodes bipunctata Brauer	5		√	–	W
Nannophya dalei occidentalis Tillyard	5		√	+	RE
Lathrocordulia metallica Tillyard	3		√	+	RE
Hesperocordulia berthoudi Tillyard	3		√	+	RE

Species	Source	Lotic	Lentic	Reservation	Distribution
Hemicordulia australiae Rambur	3,6	√	√	+	W
Hemicordulia tau Selys	5		√	+	W
Procordulia affinis Selys	3,5		√	+	RE
Synthemis cyanitincta Tillyard	2,3,5	√	√	+	RE
Gomphidae					
Hemigomphus armiger Tillyard	2	√		–	RE
Austrogomphus lateralis Selys	2,3	√	√	+	RE
Austrogomphus collaris Hagen	3,5		√	+	W
Austrogomphus ochraceus Selys	6	√		–	W
ZYGOPTERA					
Lestidae					
Austrolestes annulosus Selys	3,5		√	+	W
Austrolestes analis Rambur	5		√	+	W
Megapodagriidae					
Argiolestes minimus Tillyard	5		√	+	RE
Austroagrion cyane Selys	3		√	+	W
Xanthagrion erythroneurum Selys	6	√		–	W
EPHEMEROPTERA					
Leptophlebidae					
Bibulmena kadjina Dean	1,2,3	√	√	+	RE
Neboissophlebia occidentalis Dean	3		√	+	W
Nyungara bunni Dean	1,2	√		+	RE
Nyungara ellitasha Dean	2	√		–	W
Caenidae					
Tasmanocoenis tillyardi Lestage	2,3	√	√	+	W
PLECOPTERA					
Gripopterygidae					
Newmanoperla exigua Kimmins	1,2	√	√	+	RE
Leptoperla australica Enderlain	1,2	√		+	RE
MEGALOPTERA					
Corydalidae					
Archichauliodes cervulus Theischinger	2	√		–	W
TRICHOPTERA					
Leptoceridae					
Lectrides parilis Neboiss	1,2	√	√	+	RE
Triplectides australis Navas	3		√	+	W
Condocerus nr *aptus* Neboiss	2	√		–	RE
Notoperata tenax Neboiss	3		√	+	RE
Atriplectididae					
Atriplectides dubius Mosely	2,3	√	√	+	W
Hydroptilidae					
Acroptila globosa Wells	1,3		√	+	RE
Ecnomidae					
Ecnomina ?trulla Neboiss	1,3	√	√	+	RE
Ecnomus pansus Neboiss	1,3		√	+	W
Ecnomus turgidus Neboiss	3		√	–	W
Philorheithridae					
Kosrheithrus boorarus Neboiss	2	√		–	LE
Hydrobiosidae					
Apsilochorema urdalum Neboiss	2	√		–	RE
Taschorema pallescens Banks	2	√		–	RE
Hydropsychidae					
Smicrophylax australis Ulmer	2	√		–	RE
Polycentropodidae					
Plectrocnemia eximia Neboiss	3		√	+	W
Adectophylax volutus Neboiss	2	√		–	RE
COLEOPTERA					
Dytiscidae					
Sternopriscus ?browni Sharp	1,3	√	√	+	RE
Sternopriscus marginatus Watt	1	√		+	RE
Homoeodytes scutellaris Germar	1,3		√	+	W
Rhantus suturalis MacLeay	1	√	√	+	W
Liodessus inornatus Sharp	3		√	+	RE
Liodessus dispar Sharp	3		√	+	RE

Species	Source	Lotic	Lentic	Reservation	Distribution
Megaporus solidus Sharp	3		√	+	RE
Necterosoma darwini Babington	3		√	+	RE
Antiporus femoralis Boheman	3		√	+	W
Lancetes lanceolatus Clark	3		√	+	W
DIPTERA					
Simulidae					
Austrosimulium furiosum Skuse	1,5	√	√	+	W
Cnephia tonnoiri tonnoiri Drummond	5		√	–	W
Chironomidae					
Aphroteniella filicornis Brundin	1,2,3,5	√	√	+	W
Aphroteniella tenuicornis Brundin	5		√	–	W
Paramerina levidensis Skuse	1,2,3,5	√	√	+	W
Procladius palludicola Skuse	3,5		√	+	W
Procladius ?villosimanus Kieffer	3		√	+	W
Alotanypus dalyupensis Freeman	1,3,5		√	+	W
Coelopynia pruinosa Freeman	3		√	+	W
Corynoneura ?scutellata Winnertz	5		√	+	W
Stictocladius uniserialis Freeman	1,5	√	√	+	W
Cricotopus annuliventrus Skuse	1,2,3,5	√	√	+	W
Paralimnophyes pullulus Skuse	3,5		√	+	W
Cladopelma curtivalva Kieffer	1,3,5	√	√	+	W
Cryptochironomus griseidorsum Kieffer	1,3,5	√	√	+	W
Chironomus occidentalis Skuse	3		√	+	W
Chironomus aff *alternans* Walker	1,3,5		√	+	W
Chironomus tepperi Skuse	4		√	+	W
Dicrotendipes ?conjunctus Walker	1,3,5	√	√	+	W
Kiefferulus martini Freeman	1,3,5	√	√	+	W
Kiefferulus intertinctus Skuse	3,5		√	+	W
Paratanytarsus grimmii Schneider	5		√	+	W
Stempellina ?australiensis Freeman	3,5		√	+	W

[1] fully described species only

Table 2

Native fish species found in freshwater habitats in the Warren Bioregion. Reservation refers to their presence or absence within a nature reserve (A-class) or national park within the region. Distribution: W, widespread; RE, regionally endemic; LE, locally endemic. Sources of information include Christensen (1982), Jaensch (1992), Morgan *et al.* (1996) and Western Australian Museum records.

Species	Lotic	Lentic	Reservation	Distribution
AGNATHA				
Geotriidae				
Geotria australis Gray	√		+	W
TELEOSTEI				
Lepidogalaxiidae				
Lepidogalaxias salamandroides Mees		√	+	LE
Galaxiidae				
Galaxiella nigrostriata Shipway		√	+	RE
Galaxiella munda McDowall	√	√	+	RE
Galaxias occidentalis Ogilby	√	√	+	RE
Galaxias truttaceus Cuvier	√	√	+	W
Galaxias maculatus Jeyns	√	√	+	W
Percicthyidae				
Bostockia porosa Castelnau	√	√	+	RE
Nannopercidae				
Edelia vittata Castelnau	√	√	+	RE
Nannatherina balstoni Regan	√	√	+	RE
Plotosidae				
Tandanus bostocki Whitley	√	√	+	RE
Gobiidae				
Pseudogobius olorum Sauvage	√	√	+	W[1]
Afurcagobius suppositus Sauvage	√	√	+	RE[1]
Atheriniidae				
Leptatherina wallacei Prince, Ivantsoff & Potter	√	√	+	RE[1]

[1] not strictly a freshwater species.

species have been recorded from Margaret River, Bunbury, Gingin and Two Peoples Bay (Museum Records; Morgan *et al.* 1996) suggesting that they were once more widely distributed throughout the coastal environment of south-west Western Australia. All of these fishes are either included or have been recommended for inclusion in the list of Australian threatened fishes (Anon. 1994).

Amphibians

Twenty two species of frogs are found in the Warren Bioregion, with three of these occurring just within its boundaries (Table 3). Six of the remaining eighteen species could be considered to be locally endemic, including the south coast froglet *Ranidella subinsignifera*, the roseate frog *Geocrinia rosea*, the Walpole frog *G. lutea*, the white-bellied frog *G. alba*, the orange-bellied frog *G. vitellina* and the sunset frog (Myobatrachidae). All four *Geocrinia* species and the sunset frog have highly limited geographic distributions with *G.vitellina* and *G. alba* formally gazetted in the schedules of the Commonweath's Endangered Species Protection Act, 1992.

Table 3

Frog species known to occur within the boundaries of the Warren Bioregion. Reservation refers to their presence or absence in a nature reserve (A-class) or national park within the region. Distribution: RE, regionally endemic; LE, locally endemic. Sources of information include Main (1965), Christensen (1992), Tyler *et al.* (1994), Roberts *et al.* (in press) and Wardell-Johnson (*pers. comm.*).

Species	Reservation	Distribution
Hylidae		
Litoria adelaidensis Gray	+	RE
Litoria moorei Copeland	+	RE
Myobatrachidae		
Limnodynastes dorsalis Gray	+	RE
Heleioporus inornatus Lee & Main	+	RE
Heleioporus eyrei Gray	+	RE
Heleioporus psammophilus Lee & Main	+	RE
Heleioporus albopunctatus Gray	n/a	RE[1]
Neobatrachus pelobatoides Werner	+	RE
Crinia georgiana Tschudi	+	RE
Ranidella glauerti Loveridge	+	RE
Ranidella pseudinsignifera Main	+	RE
Ranidella insignifera Moore	n/a	RE[1]
Ranidella subinsignifera Littlejohn	+	LE[2]
gen. et sp. nov Roberts *et al.*	+	LE
Geocrinia rosea Harrison	+	LE
Geocrinia lutea Fletcher	+	LE
Geocrinia alba Wardell-Johnson & Roberts	+	LE
Geocrinia vitellina Wardell-Johnson & Roberts	-	LE
Geocrinia leai Fletcher	+	RE
Metacrinia nichollsi Harrison	+	RE
Myobatrachus gouldii Gray	n/a	RE[1]
Pseudophryne guentheri Boulenger	+	RE

[1] may be found within the boundary of the Warren Bioregion, but only peripherally; reservation status in this bioregion is therefore not applicable (n/a). [2] found in the lower south-west, a distribution broadly approximating the Warren bioregion.

The Reserve System

The Warren Bioregion extends over 1 042 000 ha with approximately 25% of that area held as national parks or nature reserves (A-class). We estimate that these reserves incorporate 86% of the aquatic faunal elements found in the region, but 7% of locally restricted species are apparently not included (Table 4). The further inclusion of locally endemic species or assemblages into the reserve system is made difficult because they are often rare as well as restricted in their distribution. Large-scale surveys across all aquatic habitats within the lower south-west would be necessary to locate all of these aquatic fauna. This is unlikely to occur in the near future and so the ability to predict the occurrence of these fauna at unsurveyed sites would be advantageous.

Predictable patterns of faunal communities often occur in wetlands with similar physical and chemical characteristics (*e.g.* Edward *et al.* 1994). Thus, it may be possible to give priority for reservation to aquatic habitats with particular biophysical traits which, elsewhere, support high levels of endemic species. Highly acidic environments and aquatic habitats associated with granite outcrops provide good examples. The four species of copepod, and two species of cladoceran found by Bayly (1992) were all acidophilic and were collected from ponds with low pH. Two species of ostracod, *Ilyodromus candonites* and *Kapcypridopsis asymmetra*, and one species of chironomid, *Allotrissocladius* sp, which are endemic to the Warren Bioregion, have been found in temporary pools associated with granite outcrops (Bayly 1982). In addition, the sunset frog, which is thought to have originated approximately 30-36 million years ago was recently found in an organic-rich swamp at the base of a granite outcrop near Walpole (Roberts *et al.* 1997).

Granite outcrops and other areas elevated above the level of the Eocene marine incursion, such as headwater regions, permanent freshwater flows, and elevated coastal locations receiving orographic rainfall, often support relictual fauna (Main & Main 1991; Hopper *et al.* 1996). These relictual habitats generally provide organically rich and permanently moist microhabitats (Main & Main 1991) for a fauna which has persisted since eustatic changes and the onset of seasonal aridity in the early Tertiary (Keast 1981). Relictual fauna are of exceptional importance from a nature conservation perspective and thus the systematic evaluation of existing reserves and

Table 4

Summary of the distribution and reservation status of aquatic fauna found in the Warren Bioregion. Number of species found, thus far, in nature reserves (A-class) or national parks within the region are shown in parentheses.

Taxa	Species[1]	Locally Endemic	Regionally Endemic	Widespread
Invertebrates	156	10 (9)	49 (41)	97 (80)
Amphibians	22	6 (5)	13 (13)	0
Fish[2]	14	1 (1)	9 (9)	4 (4)

[1] fully described species only; [2] native species only.

the inclusion of new reserves to ensure adequate representation of relictual habitats should be an urgent task.

Are the fauna protected in the reserve system?

National parks and nature reserves provide a refuge for a substantial proportion of the aquatic fauna. Their protection, however, cannot be assured unless on-reserve management procedures and activities outside the reserve system are sympathetic to the preservation and maintenance of their habitat.

The practice of conducting fuel reduction burns during late spring, summer and autumn, when the soil is dry, may inadvertently threaten some aquatic fauna either directly or through the loss of soil as habitat. Species such as *L. salamandroides* oversummer in the moist substrate of peatlands and shrublands (Pusey 1990), while other species deposit drought resistant eggs. These organically-rich soils burn readily and hence the fauna within the substratum may be lost. In addition, there may be changes in local hydrology, such as the creation of more surface pools, or improved drainage of sandy soils, which alter the proportional occurrence of habitats and some aquatic species.

Activities occurring within catchments of conservation reserves may impact adversely on the fauna. Harvey (1996) noted that Poorginup Swamp, within the Lake Muir Nature Reserve, was threatened with increased salinization as a result of nearby agricultural clearing. The swamp is the type locality for two species of water mite, *Acercella poorginup* and *Pseudohydryphantes doegi*, both of which were thought to be extinct as a result of recent hydrological changes occurring within the swamp (Harvey 1996). The latter species, however, has been found in one other location, within the Shannon River National Park (Horwitz 1994).

Adverse land-use activities within catchments are even more apparent in flowing waters where anthropogenic activity upstream may directly influence downstream habitats (*e.g.* Walker 1985; Davey *et al.* 1987; Campbell & Doeg 1989). Land clearing for agriculture in Western Australia has resulted in increased salinity (Schofield 1990) and sedimentation (Williams 1992) of many rivers and clear-fell logging which occurred in the last decade is still affecting streams today (Growns & Davis 1991; Trayler & Davis, *unpubl. obs.*). A river and stream zone system was introduced into the State Forest in the mid-70s (Anon 1977). This was later modified and today this system is estimated to include some 63 100 ha of land in the southern forest region (Anon 1992a). In addition to increasing the size of the conservation estate, these zones of undisturbed vegetation are designed to act as a buffer and minimize the effect of logging operations on the water quality of nearby streams and rivers (Anon 1992a). Large buffer zones (100 m) have been proven effective in reducing the input of sediment into second order streams (Borg *et al.* 1987), but the effectiveness of smaller zones (20-30 m), which are routinely used on these streams, has not been assessed in Western Australia. While there is ample evidence to suggest that these buffers may prevent increased sedimentation (Davies & Nelson 1994; Clinnick 1985), it is unlikely that such small buffers would prevent increases in stream salinity. Borg *et al.* (1987) found that even 100 m buffers would not prevent a rise in salinity in streams adjacent to logged coups. There is, however, some evidence to suggest that a large buffer will reduce the period that salinities remain elevated from fifteen years, as estimated by (Borg *et al.* 1988), to eight years, as documented by Growns & Davis (1991). In the past, rising salinity has not been considered important in high rainfall areas where salinities in logged catchments generally remain within the range considered acceptable for drinking water (Anon 1992b). There is, however, increasing evidence that the invertebrate fauna of this region may be intolerant of relatively small increases in salinity (Growns & Davis 1991; Trayler & Davis, *unpubl. obs.*).

The river and stream zone system plays an important role in the conservation of the endemic invertebrate fauna of lotic origin. Many of these fauna have, thus far, not been found elsewhere in the conservation estate (Table 1) and it is therefore essential that riparian buffer zones adjacent to logging coupes are of an adequate size and that these areas are managed properly. Growns (1992) argued that these buffer strips would be compromised if poorly constructed roads or accessways crossed streams to access coupes. In addition, the headwater streams within the karri forest often comprise low gradient, marshy areas with ill-defined and ephemeral water courses which may not be recognised or mapped as first-order streams. There is, therefore, potential for these areas to be overlooked and not included as part of the stream reserve system.

Translocated and exotic fish species are widespread in the waterways of the south-west with increasing anecdotal evidence that these introduced species have a serious impact on the distribution of the native fish fauna (see Morgan *et al.* 1996). Of particular concern is the translocation of piscivorous species such as the golden perch *Macquaria ambigua* and the silver perch *Bidyanus bidyanus* to private dams within the catchment of the D'Entrecasteaux National Park (Morgan *et al.* 1996). These species might further restrict populations of the native fishes if they were to escape into natural waterways.

The non-aestivating native fish species, *N. balstoni*, *Galaxias occidentalis*, *G. munda*, *Edelia vittata* and *Bostockia porosa* are particularly vulnerable to predation by introduced fishes during summer and autumn dry periods when they are forced to retreat to permanent pools and streams (Morgan *et al.* 1996). With the exception of *N. balstoni*, all of these species as well as the lamprey *Geotria australis*, were once found in abundance in the headwaters of Big Brook near Pemberton (Pen *et al.* 1988, 1991), but today their numbers have declined dramatically (Morgan & Gill 1996). In particular, *G. munda*, which was once extremely common to the system (Pen *et al.* 1988, 1991), has now disappeared upstream of the dam and this has been attributed to the recent introduction of the voracious and piscivorous redfin perch *Perca fluviatilis* to Big Brook Dam (Morgan *et al.* 1996).

Big Brook Dam also provides an ideal habitat and potential refuge for a number of other predatory species including *Salmo trutta*, *Gambusia holbrooki* and

Oncorhynchus mykiss (Morgan *et al.* 1996), whose presence may have also adversely affected the native fish fauna in the Big Brook area. While this is yet to be documented for the Warren Bioregion, elsewhere these fishes have been widely implicated in the fragmentation of fish distributions (*e.g.* Tilzey 1976; Lloyd 1990; Hutchinson 1991; Crowl *et al.* 1992).

A variety of other anthropogenic activities and threatening processes operate within nature reserves in the region. Road building activities and the construction of fire breaks, or scrub rolling for fire suppression, increase the likelihood of sediment deposition into wetland systems and enhance the potential for the spread of soil borne fungal pathogens. The effects of these activities have not been fully documented to date.

Recommendations

Conservation reserves within the Warren Bioregion in south-west of Western Australia play an important role in the protection of both the endemic and cosmopolitan aquatic fauna of the entire south-west. The wetlands within these reserves are important refuges for aquatic invertebrates, fishes and amphibians and will become increasingly so as the pressure of urbanisation and agriculture intensifies. Priority for further reservation should be given to aquatic habitats which are known to support a high level of endemic or relictual fauna. It should, however, be acknowledged that the presence of rare fauna is often difficult to detect, and unique faunal assemblages may occur in many of the undisturbed and unsurveyed wetlands of this region. Thus, all relatively undisturbed aquatic habitats in this region should be afforded some protection, at least until they have been properly surveyed.

Since aquatic habitats do not exist in isolation, they cannot be protected within a reserve system without reference to activities occurring within the catchment. Adverse impacts can arise through land clearing, the construction of dams, the introduction of exotic fishes, habitat removal, salinization, sedimentation and eutrophication associated with agriculture, mining, logging and road construction. Careful planning, which is sensitive to the fragility of aquatic habitats, as well as adequate buffers between anthropogenic activities and reserves are essential for the preservation of the fauna in this region.

The effectiveness of a reserve system is also dependent on adequate management within the reserves themselves, where it is essential that due consideration be given to the habitat requirements of the aquatic fauna. This is particularly important for aquatic environments which may be dry for six months or more each year. Seasonal and ephemeral waterbodies must be recognised as comprising an important part of the diversity of aquatic habitats and the absence of water in these environments does not necessarily preclude the presence of aquatic fauna.

Differences between management policy and practice can lead to detrimental effects on aquatic environments (see Davies & Nelson 1994). The environmental awareness of workers carrying out management procedures may be improved through training specifically in ecological and environmental issues. This important aspect of the management of natural areas currently receives little attention.

Finally, we cannot afford to be complacent with respect to the conservation of the aquatic fauna. Although reserved lands within the Warren Bioregion are extensive, these areas may not be protected in perpetuity. This has been demonstrated by the recent excision of land from the D'Entrecasteaux National Park, near Lake Jasper for the potential purpose of sand mining.

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